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# AN ANALYSIS OF THE DISSOLVED OXYGEN REGIMEN IN THE SAN JOAQUIN RIVER ESTUARY NEAR STOCKTON, CALIFORNIA BY THE CENTRAL PACIFIC RIVER BASINS PROJECT

Richard C. Bain, Jr., et al

Federal Water Pollution Control Administration
San Francisco, California

May 1968

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BY THE

CENTRAL PACIFIC RIVER BASINS PROJECT


## Abstract

This report presents data and relationships derived from a survey of the waters of the San Joaquin River Estuary near Stockton, California. Dissolved oxygen levels were measured on eight cruises from mid-July to the end of October, 1964. Each cruise included sampling during a low tide slack during the late afternoon and during the following pre-dawn period. Phytoplankton populations, nutrient level and water temperatures were also obtained at seven river stations and the Stockton Sewage Treatment Plant effluent. The pollution problems of the Stockton area are characterized and explained in part by the data from this brief study.



U. S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION
CALIFORNIA

May 1968



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THIS REPORT WAS PREPARED BY

RICHARD C. BAIN, JR.
Supervisory Sanitary Engineer

AND

WILLIAM H. PIERCE
Sanitary Engineer

ASSISTED BY

ALBERT KATKO
Aquatic Biologist

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# INTRODUCTION

## BACKGROUND, PURPOSE AND SCOPE

The San Joaquin River, during the summer months, is laden with phytoplankton, as a result of nutrient enrichment from land and waste drainage. Oxidation pond effluent from the City of Stockton, one of the major food processing centers in California, is discharged into the San Joaquin River at a point along the south-eastern edge of the Sacramento-San Joaquin River Delta. Reduced fresh waters outflows in the San Joaquin River and the heavy seasonal quantities of wastes from oxidation ponds of the City of Stockton have been accompanied by frequent low oxygen levels approaching asphyxial levels with resultant fish kills in a reach of the deepened ship channel of the San Joaquin River below Stockton. The San Joaquin River has, until recently, been a major migration route for king salmon returning from the Pacific Ocean to spawning beds in tributary streams of the San Joaquin River. Reduced king salmon runs, in recent years, may be due in part to depressed dissolved oxygen levels during the fall in the San Joaquin River downstream from Stockton.

The purpose of this study was to seek the causes of the dissolved oxygen depressions in the San Joaquin River downstream from Stockton, California. Field studies to provide data for this analysis were conducted during the period of July 13 to October 27, 1964.

The scope of the study was limited to an analysis of factors considered related to the dissolved oxygen problem. The factors included water temperature, algae, nutrients, flow and channel characteristics.

## AUTHORITY

The Federal Water Pollution Control Act, as amended, (33 U.S.C. 466 et seq.) delegates broad federal responsibilities for water pollution to the U.S. Department of the Interior. As one example the Federal Water Pollution Control Administration is required to determine the impact of Federal Water Resources development activities on water quality and present and future beneficial water uses. Studies by the Administration and its predecessor (U.S. Public Health Service Department of Health, Education and Welfare) of federal reservoir projects on the San Joaquin River and its tributary streams have pointed out the possible need for flow regulation in the San Joaquin River for water pollution control.. In addition, by letter of June 9, 1964, the California Water Quality Control Board requested that the U.S. Public Health Service investigate causes of low dissolved oxygen concentrations during summer and fall in the San Joaquin River near Stockton. The survey described in this report was conducted in response to that request and to provide information required to determine the need for storage in federal resevoirs for flow regulations for water quality control.

ACKNOWLEDGMENTS

This study was conducted with the cooperation of several agencies concerned with the problems of water quality and water resource development. The Central Valley Regional Water Pollution Control Board, Sacramento, California and the City of Stockton were particularly helpful in the conduct of this study.

Other agencies cooperating in the study were:

California Department of Water Resources
California Department of Fish and Game

Technical assistance was provided by staff of the Technical Advisory and Investigations Branch, Robert A. Taft, Sanitary Engineering Center, Public Health Service, Department of Health, Education and Welfare, Cincinnati, Ohio and the Santee Recreation Project, Public Health Service, Department of Health, Education and Welfare, San Diego, California. Both these activities have been transferred to the Federal Water Pollution Control Administration.

## SUMMARY OF FINDINGS AND CONCLUSIONS

### FINDINGS

1. A 24 mile tidal reach of the San Joaquin River near Stockton, California was sampled at two week intervals for dissolved oxygen, temperature, nutrients and phytoplankton between July and October 1964.

2. The study area included three sampling stations in the 30 foot deep dredged Stockton Ship Channel, one in the Turning Basin, three upstream in the shallow river and one composite of the Stockton oxidation pond effluent.

3. Late afternoon and early morning sampling runs were conducted on the same tidal slack to attempt measurement of diurnal changes in dissolved oxygen.

4. Net flow past Stockton varied from about 200 cfs (upstream) during the early cruises to over 1400 cfs (downstream) in the late cruises. The study area is under the influence of the Tracy Pumping Plant which draws water through Old River. Blockage of Old River and deliberate release of water from the Delta Mendota Canal, produce a net downstream flow after mid September 1964.

5. Oxidizable matter and waste flows from the Stockton ponds are highest in the late summer and early fall when peaches and tomatoes are processed.

6. Oxidizable matter accumlates in the San Joaquin River upstream of Stockton as a result of fertilization by agricultural, municipal and industrial wastes.

7. Water temperatures ranges from 24-26$^{o}$C in July and August and dropped to 16-18$^{o}$C by late October.

8. Nutrients appeared to be related to streamflow; total nitrogen and phosphorus levels increased in the ship channel when flow releases displaced to Stockton effluent downstream.

9. Dissolved oxygen levels were both stratified and depressed in the Stockton Channel and Turning Basin as compared to the well oxygenated, well-mixed shallow river stations.

10. Flow augmentation employed during the study displaced the poor quality water of the upper reaches of the deep channel downstream as evidence by higher dissolved oxygen levels in the upstream channel region and lower levels at the most downstream station.

11. The dominate flora of the river was principally diatoms while the oxidation pond contained green algae.

12. Highest phytoplankton crops were observed in the oxidation pond effluent and at river stations influenced by the pond discharge.

13. Lowest phytoplankton crops and highest zooplankton crops were observed in the Stockton deep water channel.

CONCLUSIONS

1. The dissolved oxygen depressions in the deep water channel near Stockton during summer and autumn can be attributed to at least five factors, which may work in combination to aggravate the problem. These factors include:

    a) The deep, dredged channel and settling basin, which creates lower tidal velocities, longer retention times and promotes settling of suspended matter.

    b) Oxygen demanding material discharged from the oxidation ponds operated by the City of Stockton.

    c) Oxygen demanding material swept by the river into the region from the San Joaquin Valley.

    d) Depletion of summer and autumnal flows in the San Joaquin River by storage projects and agricultural diversions.

    e) Seasonal water temperatures and light energy changes.

2. Flow augmentation of the magnitude employed during September and October 1964 is not sufficient in itself to overcome the dissolved oxygen depressions within the deep water channel near Stockton.

RECOMMENDATIONS

1. Long term biochemical oxidation demand measurements of both dissolved and suspended matter should be employed in future assessments of waste loadings since detention times for organic material entering the estuary may be measured in terms of months during the summer and fall.

2. Oxidizable waste loadings should be reduced at their source to lessen the excessive oxygen demand in the deep water channel during the summer and fall months.

3. Changes in the assimilation capacity of the deep water channel resulting from future deepening or flow releases should be evaluated.

4. The extent of reoxygenation by atmospheric and photosynthetic inputs and deoxygenation by river and waste bourn matter should receive futher study.

## DESCRIPTION OF STUDY

### STUDY AREA

The study area is located along the southeastern border of the Sacramento-San Joaquin River Delta in San Joaquin County (See Figure 1). The study was confined to a 23 mile reach of the San Joaquin River between Turner Cut (Station 1) on the north and the Mossdale Bridge (Station 7) on the south. The City of Stockton, (1960 population 86,321) with several food processing plants and other industrial activities, is the principle community in the study area.

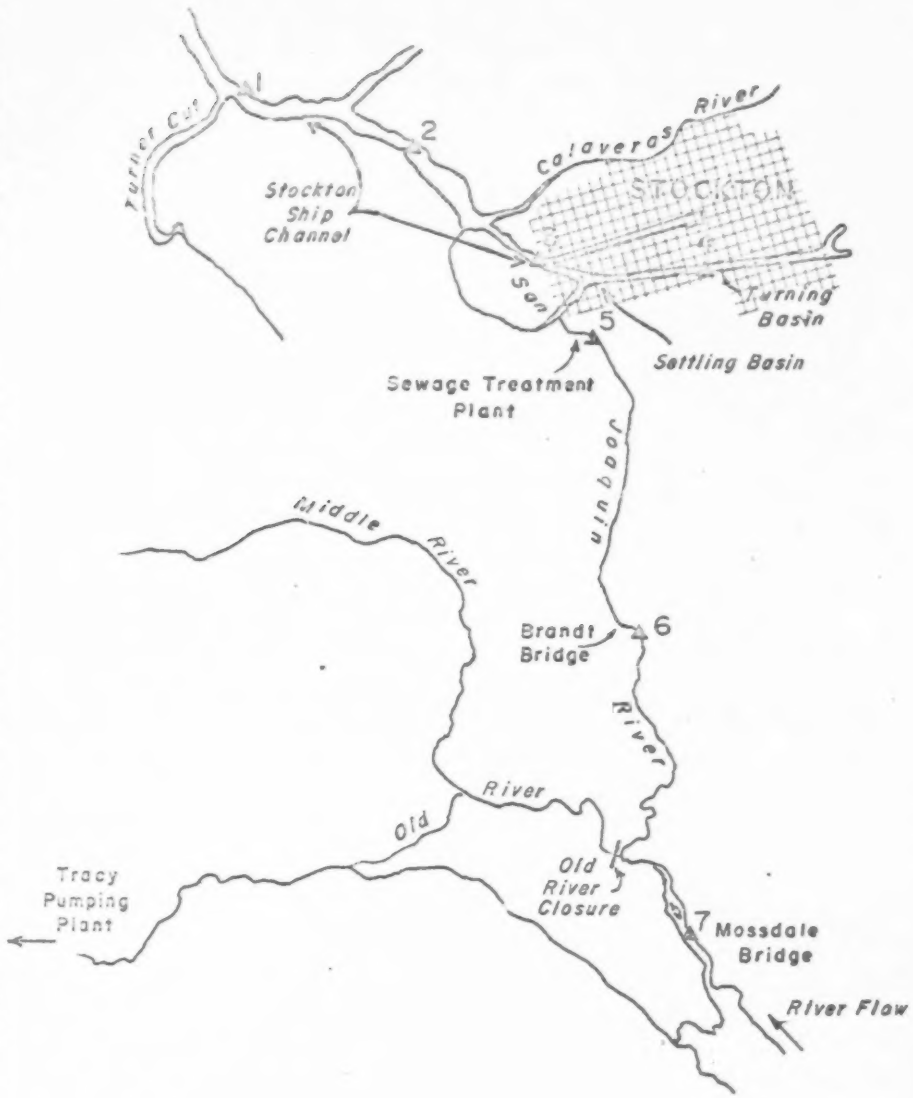
Seven sampling stations were selected and are shown on the study area map, Figure 1. Four of these stations are in the 30 feet deep Stockton ship channel; the remaining three are in the shallow San Joaquin River to the south. Samples were also collected from the Stockton Sewage Treatment oxidation pond effluent structure, which is located near Station 5. Table 1 gives a description of the sampling stations.

TABLE 1

SAMPLING STATIONS

| Station | Location Description | River Miles Above Station 1 |
|---|---|---|
| 1 | Ship Channel near Turner Cut, light 23 | 0.0 |
| 2 | Ship Channel between lights 35 and 36 | 3.7 |
| 3 | Ship Channel near light 45 | 7.1 |
| 4 | Turning Basin | * |
| 5 | River, under Santa Fe R. R. Bridge | 9.7 |
| STP | Stockton Oxidation Pond Discharge | 10.0 |
| 6 | River, Brandt Bridge | 15.6 |
| 7 | River, Mossdale Bridge | 24.3 |

* Not in hydraulic sequence, See Figure 1.




SAN JOAQUIN RIVER NEAR STOCKTON

STUDY AREA

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FIGURE 1.

The entire stream reach studied is under tidal influence. The mean tidal range, at the Mossdale Bridge, is approximately 2.4 feet; at Turner Cut, approximately 4.0 feet. From Mossdale Bridge to Stockton, a distance of approximately 16 miles, the stream is relatively shallow, ranging from 5 to 15 feet in depth at mean half tide. Stream width varies from approximately 150 to 300 feet. The channel in the remaining 9 miles from Stockton to Turner Cut, has been broadened and deepened to accommodate shipping. The channel depth averages approximately 30 feet at mean half tide.

The junction of the shallow reach and the deep ship channel has been broadened and deepened to form a settling basin for the removal of sediments. From the settling basin eastward, the deep ship channel extends to the Port of Stockton where the channel is further broadened to form a turning basin for ocean going freighters. The movement of water through this deadend reach is mainly due to tidal action.

## STUDY PERIOD

The study period extended from July 13 through October 27, 1964. During early July, the oxidation pond was not discharging; this provided an opportunity to sample the river when the entering waste load did not include oxidation pond algae. Beginning September 23, 1964, canal water releases from the Delta Mendota Canal were provided by the U.S. Bureau of Reclamation (USBR) at the request of the California Department of Fish and Game to assist migration of king salmon. A partial barrier of Old River (See Figure 1) and deliberate release of Delta Mendota Canal water into the San Joaquin River south of the sampling points provided significantly greater flushing of the San Joaquin River channel.

Thus, the sampling period selected for this water pollution control study includes (1) a period before oxidation pond effluents re-entered the river, (2) a period when natural river flow was low and net flow was upstream (due to high pumping rates at the USBR pumping facility at Tracy) and (3) a period of higher river flow with net flow downstream as provided by Delta Mendota canal releases.

Eight cruises were scheduled, each consisting of a late afternoon and a pre-dawn sampling run. The dates are listed in Table 2. Sampling was initiated at Station 1 near Turner Cut and proceeded upstream to Station 7 at Mossdale Bridge. The time required to complete a run was two-three hours, depending on river conditions and the number of samples taken.

## SAMPLING METHODS

The Central Valley Regional Water Pollution Control Board furnished an outboard cruiser, as well as a field kit for measurement of dissolved

TABLE 2

CRUISE SCHEDULE

| CRUISE | : | DATES |
|---|---|---|
| 1 | | July 13 - 14 |
| 2 | | July 30 - 31 |
| 3 | | Aug. 12 - 13 |
| 4 | | Aug. 27 - 28 |
| 5 | | Sept. 10 - 11 |
| 6 | | Sept. 26 - 27 |
| 7 | | Oct. 10 - 11 |
| 8 | | Oct. 26 - 27 |

oxygen and temperature. Surface samples (generally at 3 feet depth) were collected directly into bottles for analysis or shipment. A Kemmerer water sampler was used for collection of samples taken at depth. Samples from near the bottom were taken approximately 5 feet above the sediment.

All samples were collected on the same slack tide in order to minimize sampling errors, dur to tidal excursion. In the study area water movement due to tide is pronounced and sampling without reference to tide would introduce large inconsistencies in the data. In this study, a two week sampling interval insured that nearly the same tidal condition would occur at the desired time of day. A low tide slack was sampled in the late afternoon and early the following morning. With the effect of tide minimized, the changes in dissolved oxygen could be related to other causes, such as respiratory and photosynthetic activity related to algae and other biota.

Samples requiring chemical analysis were air mailed to the Technical Advisory and Investigations Branch (TA&I) in 1 liter polyethelene containers ("cubitainers") after being fixed with 2 ml concentrated $H_2SO_4$ to arrest bacteriological and algae activity. A 100 ml subsample was also filtered, acidified and shipped in a glass bottle for analysis of dissolved phosphorus.

Phytoplankton samples were stored in one liter polyethelene containers and preserved with 20 ml neutral formalin. These samples were shipped to Santee, California for analysis. Albert Katko, FWPCA, Aquatic biologist, made all algal identifications, counts and biomass measurements.

SAMPLE ANALYSIS

Each cruise included sampling for water temperature, dissolved oxygen, the nitrogen series, total and dissolved phosphorus, and phytoplankton populations. The analytical methods used in all chemical tests except nitrate were based on Standard Methods 11th Edition. The nitrate-nitrogen test was by the brucine method developed by Jenkins and Medsker (1). The phytoplankton counts were by the Sedgewick Rafter slide method as described in Plankton Population Dynamics (2).

## HYDRAULICS

During the summer and fall months, the San Joaquin River flow south of the study area is measured at Vernalis, the most northerly stream gage on the river not subject to tidal influence (18 miles south of Mossdale Bridge). Stream flow at this point and southward along the Valley floor is largely made up of agricultural return flow, irrigation canal wastage and treated sewage effluents.

Mean monthly flows at the Vernalis gage for July - October for the years 1960-1964 are tabulated below for reference:

TABLE 3

SAN JOAQUIN RIVER FLOW[a]
(Mean Monthly Flow in Cubic Feet Per Second)

| : | July | : | August | : | September | : | October |
|---|---|---|---|---|---|---|---|
| 1960 | 222 | | 267 | | 385 | | 713 |
| 1961 | 104 | | 151 | | 321 | | 410 |
| 1962 | 856 | | 694 | | 993 | | 1454 |
| 1963 | 1822 | | 1095 | | 1515 | | 2677 |
| 1964 | 383 | | 440 | | 900 | | 1411 |

(a) U. S. Geological Survey - Surface Water Records for California

Old River, several Delta channels, the Calaveras River and several tidal sloughs are tributary to the San Joaquin River study area. Except for the Old River, these tributaries may be considered of minor importance to the hydraulics of the stream.

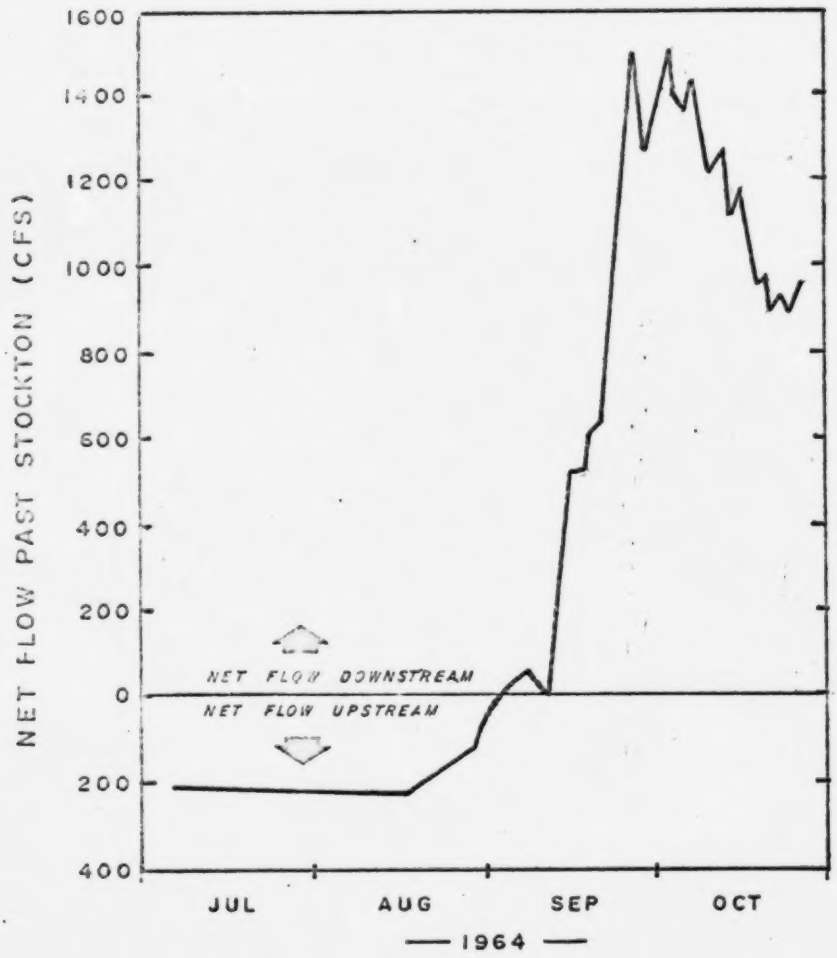
Old River joins the San Joaquin River below Mossdale Bridge (See Figure 1) and meanders westward toward the Tracy Pumping Plant. The Tracy Pumping Plant diverts water from the Delta waters for delivery to irrigators in the San Joaquin Valley. This diversion, during summer months, often exceeds 4,000 cubic feet per second (cfs). Most of this water is drawn across the Delta from the Sacramento River; however, water is also drawn from the San Joaquin River via Old River. Since 1958, pumping at Tracy, coupled with low flows in the San Joaquin

River, has caused net flow reversals in the San Joaquin River downstream from its confluence with Old River.

Other diversions from the San Joaquin River in the study area are minor and have a negligible effect on the hydraulics of the stream. The net flow of water through the stream reach is, therefore, primarily dependent on the amount of return flow in the San Joaquin River and diversions at the Tracy Pumping Plant.

Low flow in the San Joaquin River coupled with diversions at Tracy Pumping Plant resulted in net flow reversals in the study area during the months of July and August, averaging approximately 210 and 18 cfs (net upstream flow) respectively. During the first half of September, a net downstream flow passing Stockton averaged approximately 34 cfs. The California Department of Fish and Game, and the California Resources Agency Committee on Lower San Joaquin River Salmon Migration Problems, recommended a partial closure of Old River, at its confluence with the San Joaquin River increased almost immediately to approximately 500 cfs. The flow was further augmented on September 23 by water diverted at the Tracy Pumping Plant and released into the San Joaquin River, via the Delta Mendota Canal, at points south of the study area in the San Joaquin Valley. On September 25, the estimated flow passing Stockton was 1162 cfs. Further modification of the stream flow was effected on October 6, when the closure at Old River was altered to increase flow into Old River. Throughout the remainder of the study period, flow passing Stockton ranged between 888 and 1515 cfs. Figure 2 illustrates the estimated net flow passing Stockton during the study period.

Travel times through the stream reach are shown on Figure 3. The long detention time in the deep ship channel is particularly significant. A net downstream flow of 200 cfs takes about 8.7 days of travel time or 1.8 miles per day from Old River to the settling basin; whereas, the travel time is approximately 33.5 days or 0.2 miles per day from the settling basin to Turner Cut.




SAN JOAQUIN RIVER NEAR STOCKTON

NET FLOW PAST STOCKTON
JULY - OCTOBER 1964

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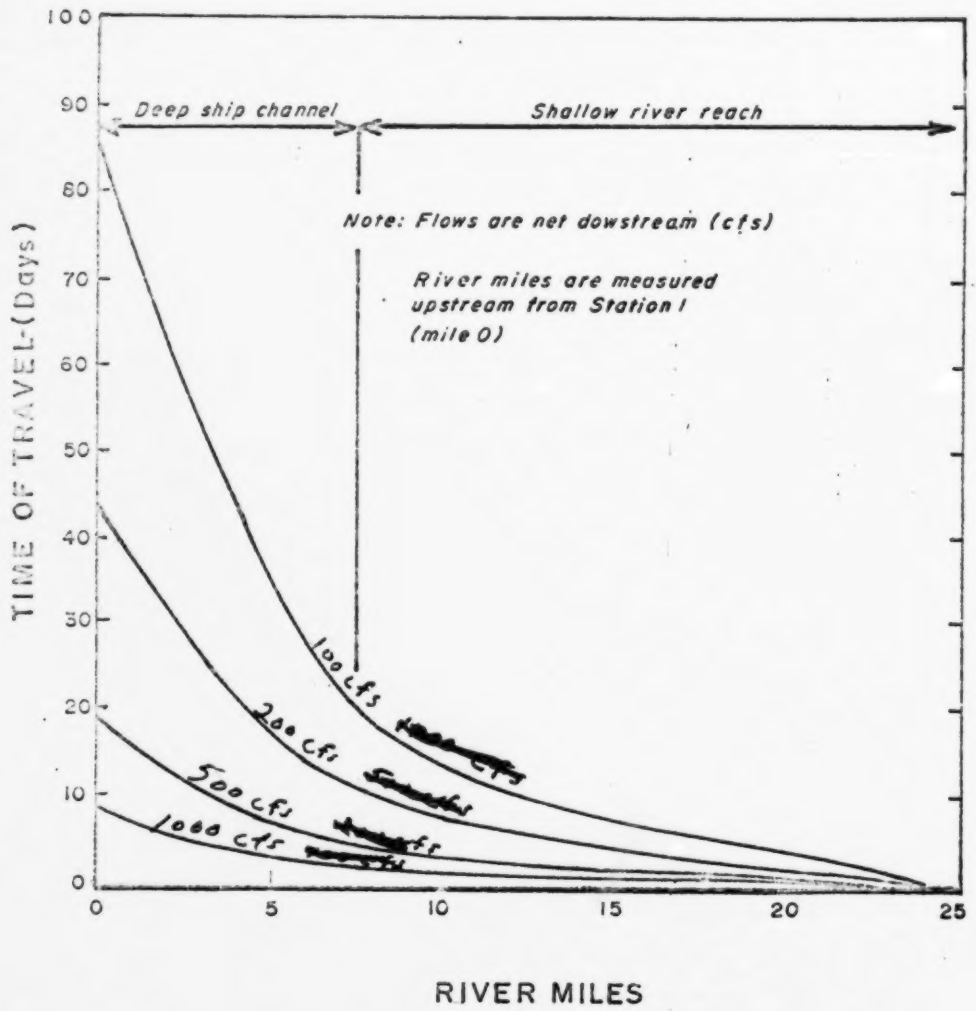
FIGURE 2




SAN JOAQUIN RIVER NEAR STOCKTON

TIME OF TRAVEL

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FIGURE 3

## WASTE DISCHARGES

### MUNICIPAL - INDUSTRIAL WASTES

The City of Stockton is one of the major food processing centers in California. The processing of asparagus and spinach in April marks the start of the cannery season, which usually extends through December when prunes and pumpkins are processed. The heaviest production period occurs in August, September and October with the processing of peaches and tomatoes. Other fruits and vegetables, which are handled in Stockton canneries include apricots, cherries, and peas. The City of Stockton provided waste treatment for six food processing companies in 1964.

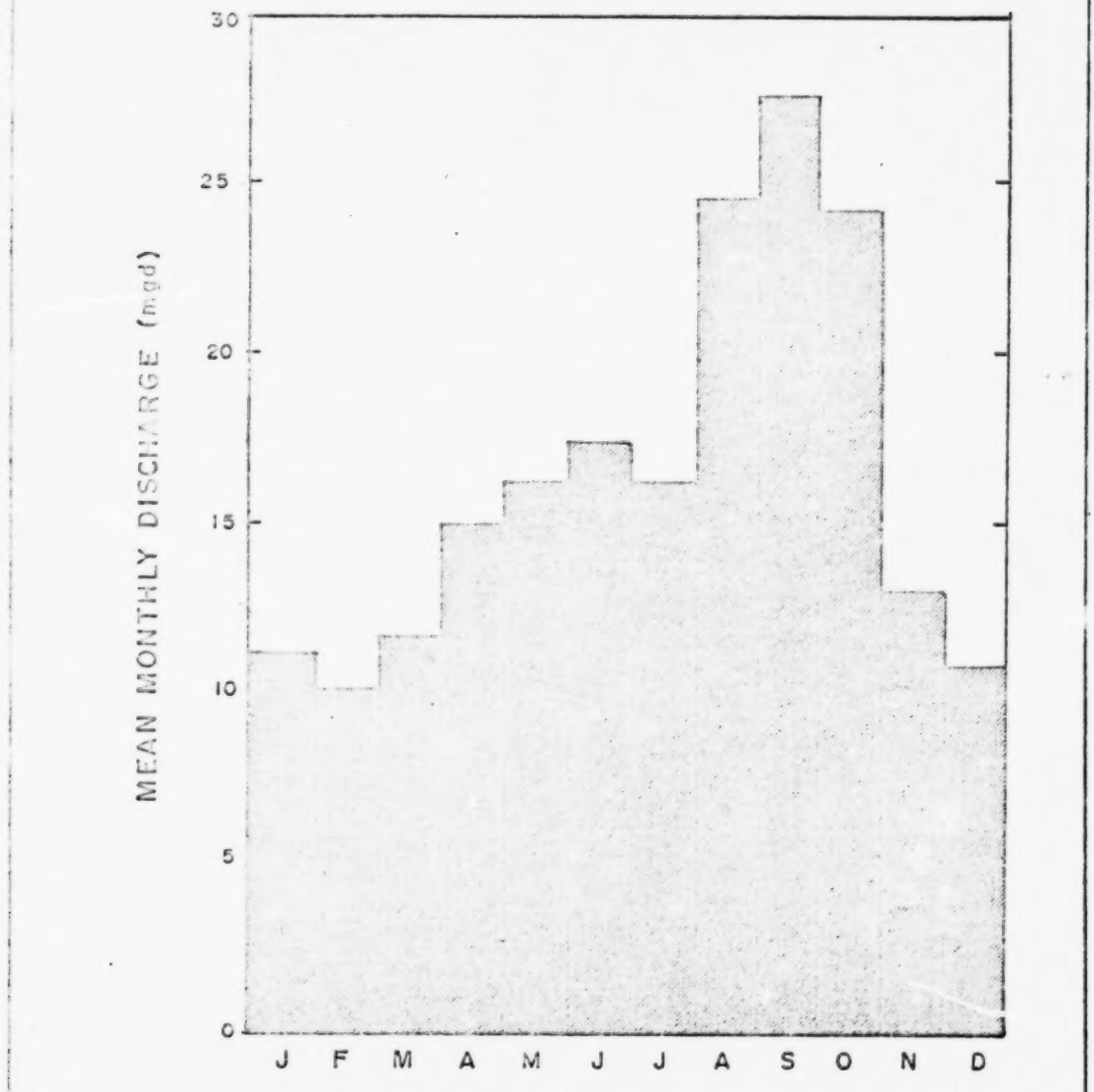
For the three year period, 1961-1963, the mean monthly raw waste flow ranged from 10.1 million gallons per day in February to 27.2 million gallons per day in September. For the same period, the mean monthly raw waste load varied from 19,400 pounds of 5 day Biochemical Oxygen Demand (BOD) per day in February to 92,000 pounds of 5 day BOD per day in August. Figures 4 and 5 present mean monthly raw waste flows, and raw waste loads for the period 1961-1963.

Waste treatment facilities at Stockton consist of secondary treatment by trickling filters and retention in two oxidation ponds. The two oxidation ponds occupied approximately 200 acres (1964) and provide a mean detention, at maximum monthly flow, of approximately 10 days. Ammonia was added to the nitrogen deficient waste at the influent to the trickling filters and before the oxidation pond intake.

Prior to the study period, maintenance work on the oxidation ponds and secondary treatment unit resulted the following conditions:

| Time Period | Disposal of Waste |
|---|---|
| Prior to April 30 | Secondary effluent to stream |
| April 30 through May 29 | Primary effluent to stream |
| May 30 through June 5 | Secondary effluent to stream |
| June 6 through June 14 | Pond #1 being filled |
| June 15 through June 28 | Secondary effluent to stream |
| June 29 through July 14 | Pond #2 being filled |
| July 15 through end of study | Pond effluent to stream |

After July 15, the daily discharge from the ponds varied widely and ranged from 2.5 to 43.1 million gallons per day.




SAN JOAQUIN RIVER NEAR STOCKTON

CITY OF STOCKTON
WASTE DISCHARGE
(Mean Monthly)
1961 - 1963

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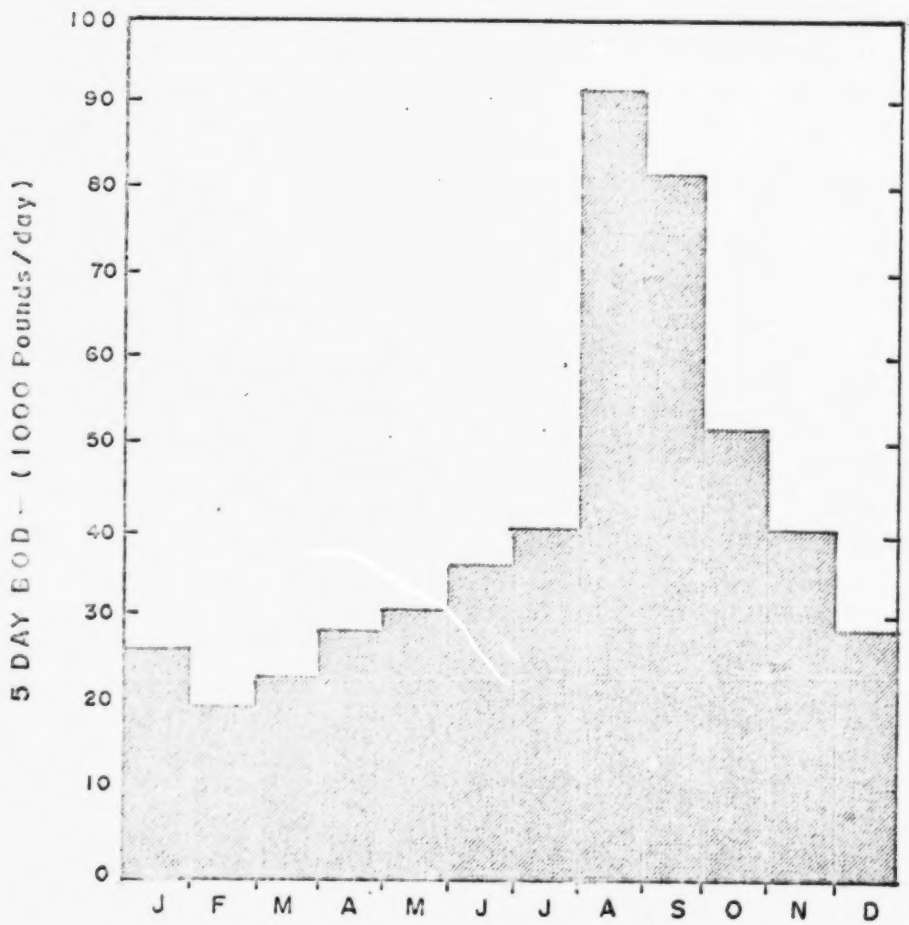
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA



FIGURE 4




SAN JOAQUIN RIVER NEAR STOCKTON

RAW WASTE LOADING
(Mean Monthly)
1961 – 1963

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SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA



FIGURE 5

For each of the cruises, except cruise 1 when the ponds were not discharged, a 24 hour composite sample of the Stockton oxidation pond effluent was prepared from four samples collected at six hour intervals. Samples were analyzed for nitrogen and phosphorus forms, as well as phytoplankton numbers, kinds and biomass.

## AGRICULTURAL DRAINAGE

There are several small industrial waste and irrigation return water discharges in the study area which were not sampled. Agricultural drainage and other wastes entering the San Joaquin River upstream from the study area, were not sampled separately, but their overall influence on the river is apparent in the quality of the waters sampled at Mossdale (Station 7) as compared with quality upstream from the agricultural and urban complex. Table 4 contains data collected by the California Department of Water Resources on the San Joaquin River at Mossdale, Patterson, Mendota and Biola.

TABLE 4

MEAN QUALITY OF SAN JOAQUIN RIVER[a]
(July-October 1962)

| | Mossdale | Patterson | Mendota | Biola |
|---|---|---|---|---|
| BOD (5 day) | 5.3 | 5.4 | 0.8 | 0.5 |
| Total Nitrogen | 0.92 | 1.65 | 1.00* | 0.42 |
| Total Phosphorus | 0.22 | 0.28 | 0.18 | 0.04 |
| Dissolved Solids | 543 | 545 | 281 | 47 |

(a) Values listed are in milligrams per liter.

* Single high value reported influenced average.

These data demonstrate that considerable oxygen demand is developed in the river downstream from Mendota. This demand is principally the respiration and decay of plankton, which reach large populations in the portions of the river enriched by agriculture drainage and sewage. Data on plankton populations are discussed in the following sections.

## STUDY RESULTS

Information collected during the course of this study are described in three succeeding sections on physical, chemical, and biological data.

### PHYSICAL DATA

Hydraulic information was presented in the proceeding section along with discharge data on the Stockton Sewage Treatment Plant.

Water temperatures were essentially constant with respect to depth in both the shallow well-mixed river and in the deep water ship channel. The range of water temperatures was approximately 24° - 26°C in July and August and dropped to 16° - 18° C by late October. Water temperatures observed during the morning cruises were generally 1 - 2°C lower than in the afternoon cruise. Station 1 was coolest in July and warmest in October after river water temperatures had dropped.

Light penetration in the study area is quite limited. No organized light penetration study was conducted, but visual observations and field tests made since 1964 indicate that transparency values (Secchi disc) are often about one foot or less in the shallow river and one to three feet in the ship channel during the summer and early fall.

### CHEMICAL DATA

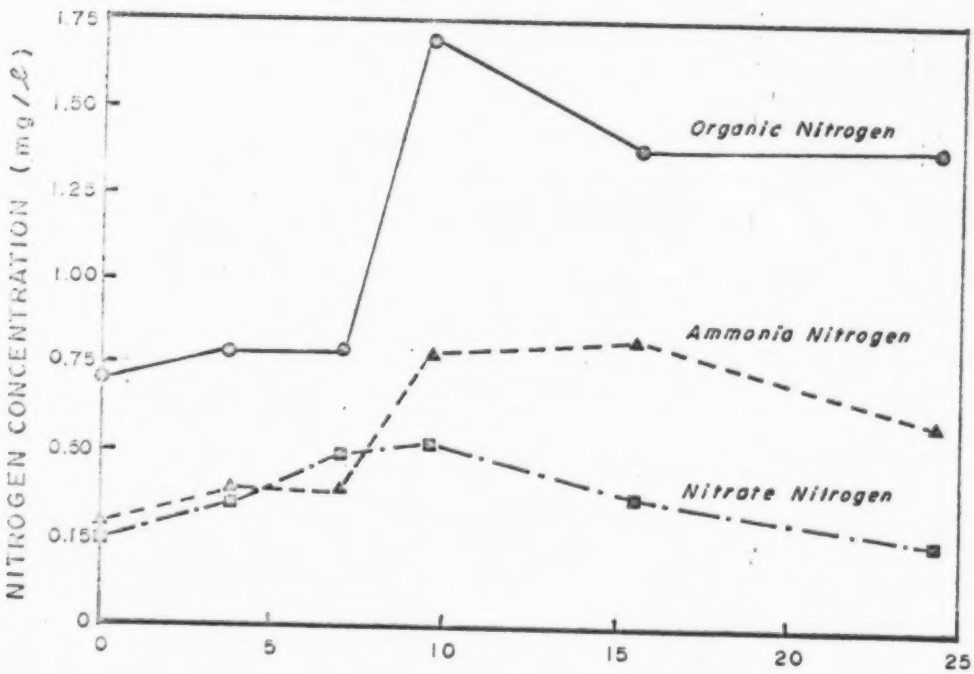
Chemical data include nutrient analyses performed by TA&I and field titrations of dissolved oxygen.

#### Nutrients

A summary of total nitrogen (N) and total phosphorus (P) from the samples (where all forms were reported) is given in Table 5. A plot of mean organic, ammonia and nitrate nitrogen for cruises 1-4 is presented in Figure 6. In the early cruises (1-4) when net flow was upstream, the ship channel stations had lower concentration of nutrients than occurred after flow was augmented. Quite the opposite relationship for phosphorus appears evident in the river stations. Total nitrogen appears more constant in the shallow river.

#### Dissolved Oxygen

Dissolved oxygen (DO measurements were made on the same tidal slack late in the afternoon and early in the morning on each of the eight cruises. Measurements were also taken at several depths in the ship channel and at deep sections in the river. The results can thus be compared according to spatial variations (with water depth and from one station to another) and temporal variations (between the afternoon and morning cruises, or between the bimonthly sampling runs).




SAN JOAQUIN RIVER NEAR STOCKTON

NITROGEN CONCENTRATION
(CRUISES 1-4)

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FIGURE 6

In the ship channel (Stations 1-4) the DO near the bottom was generally lower than near the surface. Table 6 includes the mean DO at the top and bottom for all stations for both the evening and early morning cruises. The top and bottom DO values for Station 6 indicate this shallow river section is well-mixed, as compared with the deeper stratified ship channel.

TABLE 5

NUTRIENTS - SAN JOAQUIN RIVER STATIONS

| Station Number | Location | Total Nitrogen (a) Cruises (1-4)(b) | Total Nitrogen (a) Cruises (6-7)(c) | Total Phosphorus (a) Cruises (1-4)(b) | Total Phosphorus (a) Cruises (6-8) |
|---|---|---|---|---|---|
| 1 | Ship Channel | 1.3 | 2.4 | 0.12 | 0.18 |
| 2 | Ship Channel | 1.5 | 3.2 | 0.22 | 0.25 |
| 3 | Ship Channel | 1.7 | 3.5 | 0.23 | 0.32 |
| 4 | Turning Basin | 1.9 | 3.0 | 0.16 | 0.21 |
| 5 | River | 3.0 | 2.6 | 0.44 | 0.25 |
| 6 | River | 2.4 | 2.8 | 0.32 | 0.17 |
| 7 | River | 2.2 | 2.4 | 0.25 | 0.16 |

(a) Values listed are in milligrams per liter.

(b) Cruise 5 omitted since streamflow was being altered from net upstream (Cruise 1-4) to net downstream flow (Cruises 6-8).

(c) No organic nitrogen data for Cruise 8.

TABLE 6

MEAN DISSOLVED OXYGEN CONCENTRATIONS (a)
(Cruises 1-8)

| Station | Evenings | | Mornings | |
|---|---|---|---|---|
| | Top | Bottom | Top | Bottom |
| 1 | 6.6 | 5.9 | 6.2 | 6.0 |
| 2 | 6.4 | 4.8 | 5.2 | 5.2 |
| 3 | 8.0 | 4.8 | 5.3 | 5.1 |
| 4 | 7.9 | 4.5 | 5.4 | 4.6 |
| 5 | 9.0 | --- | 6.4 | --- |
| 6 | 11.7 | 11.4 | 8.3 | 7.9 |
| 7 | 10.9 | --- | 8.6 | --- |

(a) Values listed are in milligrams per liter.

Profiles of the average afternoon and morning DO levels reflect the different character of the shallow river reach and the ship channel section, as well as the photosynthetic activity of algae. The higher DO (both top and bottom) in the shallow river section, as compared with the deep ship channel is clearly evident.

The DO concentrations measured during the study are presented in Table 7. The afternoon and morning DO concentrations at all stations for cruises 1-4 are plotted in Figure 7. A discussion of the relationships between photosynthetic activity, algal respiration, BOD and dissolved oxygen changes will be given in a later section.

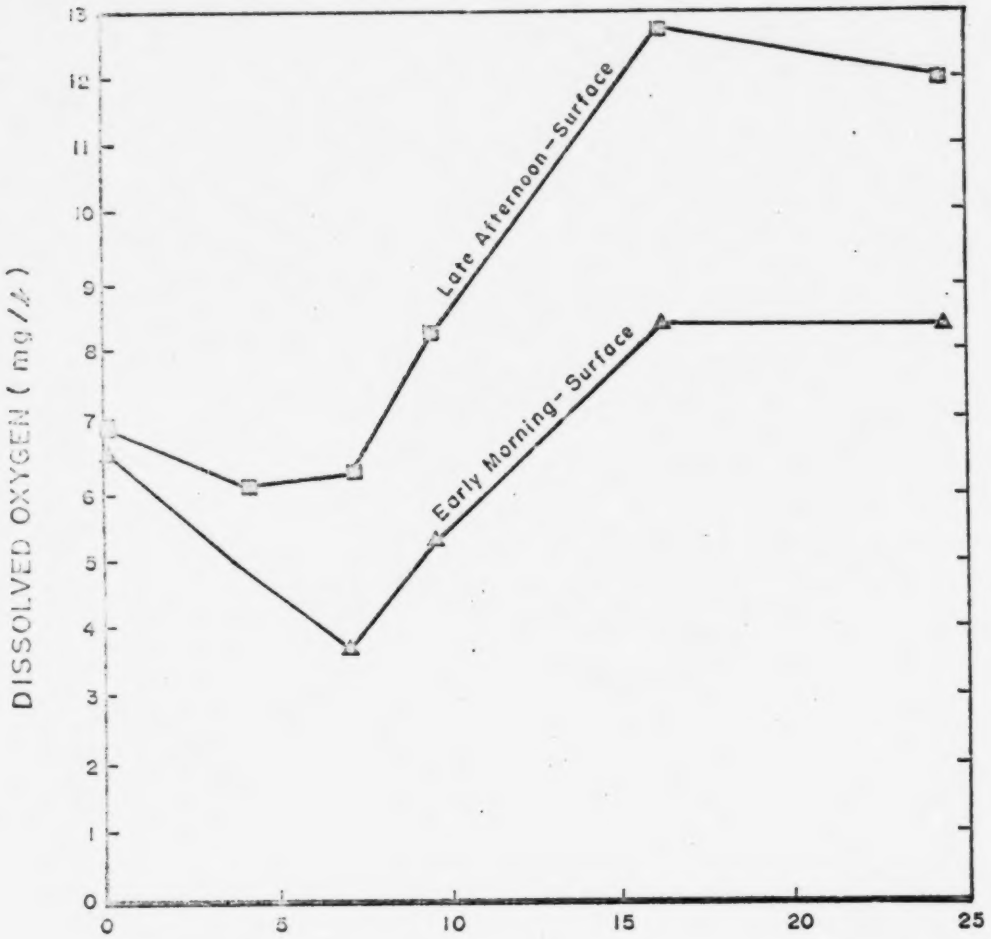
Dissolved oxygen levels in the ship channel during cruises 1-5 as compared with cruises 6-8 demonstrate the effect of increased river flow from late September through October. For example, at Station 3 during cruises 1-4, the DO of all ten bottom samples (5 morning and 5 afternoon) was equal to or less than 5.0 mg/l; whereas, during cruises 6-8 the DO of the six bottom samples was always greater than 6.0 mg/l. The poor quality waters of Station 3 appears to have been displaced downstream by the flow release since DO levels dropped at Station 1 during cruises 6-8. The average bottom DO at Station 1 during cruises 1-4 was 6.2 mg/l as contrasted with 5.3 mg/l during cruises 6-8.

TABLE 7

OBSERVED DISSOLVED OXYGEN CONCENTRATIONS *

| Station | CRUISE 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PM | AM | PM | AM | PM | AM | PM | AM | PM | AM | PM | AM | PM | AM | PM | AM |
| 1 | 7.0 | 6.0 | 5.8 | 5.6 | 7.0 | 7.2 | 6.8 | 6.4 | 8.0 | 7.2 | 6.8 | 6.0 | 5.6 | 5.0 | 5.5 | 6.2 |
| | 6.0 | 5.8 | 5.6 | 5.4 | 6.1 | 7.4 | 6.8 | 6.2 | 6.8 | 7.4 | 5.6 | 5.0 | 5.0 | 5.0 | 5.4 | 5.8 |
| 2 | 6.0 | 5.4 | 4.2 | 3.8 | 6.2 | 5.0 | 6.0 | 5.0 | 8.1 | 4.6 | 6.2 | 5.4 | - | 5.6 | 8.4 | 7.0 |
| | - | 5.8 | 3.0 | 4.2 | 4.7 | 5.4 | 4.6 | 5.2 | 4.2 | 4.2 | 4.8 | 5.0 | 5.2 | 5.6 | 6.0 | 6.6 |
| 3 | 7.0 | 4.0 | 4.0 | 2.8 | 5.2 | 4.3 | 7.4 | 3.2 | 8.2 | 4.3 | 11.0 | 9.2 | 11.4 | 7.2 | 10.1 | 7.6 |
| | 4.0 | 4.0 | 3.8 | 2.6 | 4.0 | 5.0 | 1.8 | 3.2 | 4.0 | 3.5 | 8.0 | 8.0 | 6.2 | 6.8 | 6.8 | 7.6 |
| 4 | 5.6 | 3.8 | 6.6 | 5.8 | 7.8 | 6.4 | 10.2 | 4.8 | 8.0 | 5.4 | 5.4 | 5.0 | 8.4 | 4.7 | 11.6 | 7.0 |
| | 3.2 | 3.7 | 4.4 | 4.8 | 5.2 | 6.2 | 5.0 | 4.6 | 2.6 | 2.2 | 3.0 | 4.8 | 6.0 | 4.4 | 7.0 | 5.8 |
| 5 | 7.9 | 5.2 | 8.0 | 5.2 | 7.2 | 6.8 | 8.6 | 3.2 | 9.4 | 6.0 | 14.0 | 9.5 | 8.4 | 7.0 | 8.4 | 8.2 |
| | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 | 13.0 | 9.8 | 12.4 | 8.8 | 12.4 | 8.8 | 13.6 | 10.1 | 12.4 | 9.4 | 12.6 | 8.4 | 8.6 | 6.8 | 8.3 | 7.0 |
| | - | - | 12.6 | - | 12.2 | 9.0 | 13.4 | - | 12.5 | 9.6 | 12.6 | 8.4 | 8.6 | 6.8 | 8.2 | 7.4 |
| 7 | 11.8 | 7.4 | 8.0 | 5.6 | 11.2 | 10.0 | 14.0 | 11.4 | 15.1 | 13.0 | 11.2 | 6.8 | 8.2 | 6.7 | 8.0 | 8.0 |
| | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

* Top / Bottom




SAN JOAQUIN RIVER NEAR STOCKTON

DISSOLVED OXYGEN
CRUISE 1-5

DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA



FIGURE 7

In the river reach the DO differences (from afternoon to morning) were less marked during cruises 7 and 8, as compared with the early cruises. This difference may be a result of dilution of planktonic algae and the presence of lower water temperatures in October, which would limit the activity of the algae present.

BIOLOGICAL DATA

Phytoplankton were identified and enumerated at each station and at all depths sampled on either the morning or the afternoon run of each cruise. In addition, a sample from the oxidation pond discharge was also examined on each but the first cruise when no pond discharge occurred.

The phytoplankton community of the San Joaquin River is to a certain extent homogenous, but differences in the kinds, numbers, and distribution of phytoplankton are apparent from the data. Qualitative differences are most obvious between the oxidation pond and the stations more remote from the pond discharge location. Table 8 includes a listing of all the algal genera found at the stations. Many of these genera were not numerous in any samples and do not make up a very significant portion of the biomass; however, the presence of certain genera may have meaning when their environmental requirements are better know. Table 9 includes a listing of the most dominant genera at each station. Generally, the dominant phytoplankters in the river and the ship channel are the centric diatoms Cyclotella and Coscinodiscus. The dominant genera in the oxidation pond are green algae Chlorococcum, Chlorella, and Scenedesmus, and the diatom Cyclotella.

Data from the first cruise indicate high numbers of phytoplankton present at the river stations (See Figure 8). The second cruise showed a reduction, followed by a general increase toward peak populations by cruise four. During the last three cruises when net downstream flow was high, there was a continued increase in phytoplankton at the four channel stations and a decrease at the three shallow river stations. Cyclotella maintained its dominance, but Coscinodiscus was displaced by green algae at Station 7.

During the August cruises, the Stockton oxidation pond experienced a bloom of Cyclotella and Nitzschia. This bloom coincides with the occurrence of over 5,000 inert centric diatom shells per millimeter in bottom samples at Station 3 during August as compared with less than 2000 in late July. A sharp decline in the diatom populations in the ponds occurred through the September cruises followed by a bloom of Scenedesmus and Schroderia by October.

Table 10 contains total phytoplankton counts, inert diatoms, biomass and the number of genera for each of the seven station (both top and bottom samples) for each of eight cruises. Table 11 contains algal

TABLE 8

DISTRIBUTIONS OF LIVE PHYTOPLANKTON

| | 1 | 2 | 3 | 4 | SSTP | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Coccoid Green Algae | | | | | | | | |
| Actinastrum | | X | X | X | X | X | X | X |
| Ankistrodesmus | | X | X | X | X | X | X | X |
| Chlorella | X | X | X | X | X | X | X | X |
| Chlorococcum | X | X | X | X | X | X | X | X |
| Closterium | | X | | | X | X | | |
| Coelastrum | X | X | X | X | X | X | X | X |
| Crucigenia | X | X | X | X | X | X | X | X |
| Dictyosphaerium | | X | X | X | X | X | X | X |
| Elakatothrix | | | | X | | X | X | |
| Golenkinia | | | X | | X | X | | X |
| Kirchneriella | | X | X | X | X | X | X | X |
| Lagerheimia | | X | X | | X | X | | |
| Micractinium | | X | X | X | X | X | X | X |
| Oocystis | X | X | X | X | X | X | X | X |
| Pediastrum | X | X | X | X | X | X | X | X |
| Polyedriopsis | | X | | | X | X | | |
| Scenedesmus | X | X | X | X | X | X | X | X |
| Schroederia | | X | X | X | X | X | X | |
| Staurastrum | | | | X | | | | |
| Tetraedron | X | X | X | X | X | X | X | X |
| Treubaria | | | | X | | | | X |
| Filamentous Green Algae | | | | | | | | |
| Stichococcus | X | | X | | | | X | X |
| Coccoid Blue Green Algae | | | | | | | | |
| Agmenellum | X | X | X | | | X | X | X |
| Anacystis | X | X | | X | | X | X | X |
| Filamentous Bluegreen Algae | | | | | | | | |
| Anabaena | | | | X | | | | X |
| Gleotrichia | | X | X | | | X | X | X |
| Oscillatoria | | X | X | X | X | X | X | X |
| Phormidium | | | | X | X | X | X | X |
| Rahpidiopsis | | | | | X | | | |

TABLE 8 (continued)

DISTRIBUTION OF LIVE PHYTOPLANKTON

| | 1 | 2 | 3 | 4 | SSTP | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Green Flagellates | | | | | | | | |
| Carteria | X | X | X | X | | X | X | X |
| Chlamydomonas | X | X | X | X | X | X | X | X |
| Chlorogonium | X | | | | | X | | |
| Lepocinelis | | | X | X | | X | X | |
| Phacus | | X | | X | | X | | X |
| Pteromonas | | X | | | | | | |
| Sphaerellopsis | | | | X | X | | | |
| Euglena | X | X | X | X | X | X | X | X |
| Ochre Pigmented Flagellates | | | | | | | | |
| Cryptomonas | X | X | X | | | | X | X |
| Dinobryon | | | X | | | | | |
| Glenodinium | X | X | X | X | | X | X | X |
| Strombomonas | | | | | | | | |
| Trachelomonas | X | X | X | | | | X | X |
| Pandorina | | | | X | | | | X |
| Peridinium | | | | X | | | X | |
| Diatoms | | | | | | | | |
| Coscinodiscus | X | X | X | X | | X | X | X |
| Cyclotella | X | X | X | X | X | X | X | X |
| Melosira | X | X | X | X | X | X | X | X |
| Stephanodiscus | | X | X | X | | | X | |
| Amphora | | | | | | | | X |
| Caloneis | | | X | | | X | | |
| Cocconeis | X | X | | | | X | X | |
| Cymatopleura | | | | | | | | X |
| Cymbella | | X | | | | | X | |
| Epithemia | X | | | | | | | |
| Gyrosigma | | | X | | | | | |
| Navicula | X | X | X | | X | X | X | X |
| Nitzschia | X | X | X | X | X | X | X | X |
| Pinnularia | | | | | | | X | |
| Pleurosigma | | | | | | | X | |
| Rhoicosphenia | | | | | | | | |
| Surirella | X | X | X | | | | | |
| Synedra | | X | X | | | X | X | X |

TABLE 9

DOMINANT ALGAL GENERA

CRUISE

| Station | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | BA<br>CD | BA<br>GC | AB<br>ST | BA<br>ES | BA<br>C | BA<br>NI | BA<br>NC | BN<br>AV |
| 2 | BA<br>CG | BA<br>NC | BA<br>CN | BA<br>DN | BA<br>CS | BA<br>NS | BA<br>HC | BN<br>AV |
| 3 | BA<br>NQ | BA<br>NC | BE<br>AH | SB<br>AH | BA<br>NH | BN<br>AS | BN<br>AS | NB<br>AO |
| 4 | BA<br>GI | AB<br>MC | AB<br>EH | AS<br>BN | AB<br>HU | BA<br>SN | BN<br>AF | NB<br>VA |
| 5 | BA<br>HN | BA<br>HN | EB<br>AI | BH<br>AE | BA<br>NH | BA<br>NS | BA<br>NS | NB<br>AS |
| STP | -- | HN<br>IS | BG<br>RH | HB<br>EG | HN<br>IB | NH<br>BI | NO<br>BG | NK<br>OB |
| 6 | BA<br>NM | BA<br>CN | BA<br>CR | AB<br>CN | BA<br>SN | BA<br>NS | BH<br>AN | BS<br>EA |
| 7 | BA<br>PM | BA<br>NQ | BA<br>SN | BS<br>EF | BE<br>SN | BH<br>JN | BE<br>FL | BS<br>HE |
| Vernalis | SY<br>IF | CX<br>SI | CN<br>XS | | CS<br>XL | | | SY<br>NC |

Genera Key

DIATOMS

Centric
- A Coscinodiscus
- B Cyclotella
- C Melosira

Pennate
- D Navicula
- E Nitzschia

GREEN ALGAE

Coccoid
- X Actinastrum
- F Ankistrodesmus
- G Chlorella
- H Cloroccum
- I Coelastrum
- J Kirchneriella
- K Lagerheimia
- L Micractinium
- M Oocystis
- N Scenedesmus
- O Schroderia
- Y Other

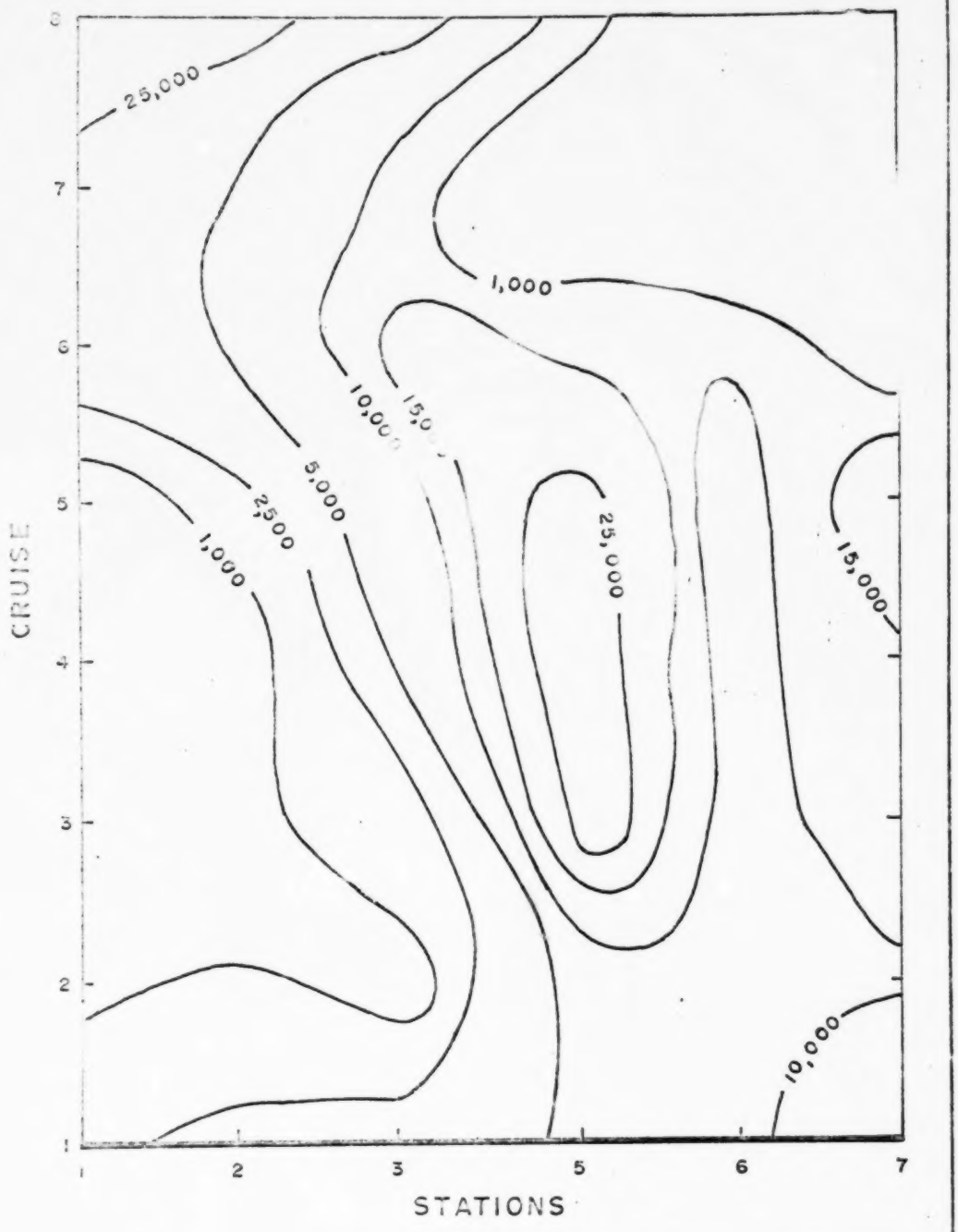
Filamentous
- P Stichococcus

BLUE GREEN ALGAE

Filamentous
- Q Gleotrichia
- R Oscillatoria

GREEN FLAGELLATES
- S Chlamydomonas
- T Chlorogonium
- U Phacus

DINOFLAGELLATES
- V Glenodinium




SAN JOAQUIN RIVER NEAR STOCKTON

PHYTOPLANKTON COUNTS (org/ml)

DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 8

| Station | Item | CRUISE | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | Total Cells (org/ml) | 3,360 / 4,192 | 1,502 / 1,443 | 1,083 / 2,037 | 1,655 / 1,462 | 445 / 1,462 | 6,229 / 5,406 | 5,028 / 6,815 | 2,418 / 3,119 |
| | Inert Diatoms (org/ml) | 1,230 / 1,731 | 1,152 / 1,029 | 446 / 1,526 | 891 / 953 | 191 / 380 | 762 / 760 | 1,148 / 2,042 | 701 / 828 |
| | Biomass (ml/l) | 12.9 / 20.8 | 3.4 / 3.7 | 2.6 / 9.2 | 11.0 / 4.7 | 3.2 / 6.7 | 28.0 / 26.7 | 14.4 / 15.5 | 12.5 / 9.5 |
| | No. of Genera | 9 / 12 | 9 / 6 | 5 / 8 | 5 / 4 | 2 / 2 | 3 / 11 | 10 / 12 | 4 / 6 |
| 2 | Total Cells (org/ml) | 4,594 | 2,418 / 5,190 | 1,339 / 3,627 | 958 / 2,928 | 2,418 / 4,388 | 6,301 / 9,664 | 6,301 / 6,044 | 6,935 / 7,253 |
| | Inert Diatoms (org/ml) | 1,231 | 1,336 / 4,172 | 701 / 2,608 | 374 / 2,354 | 639 / 2,863 | 638 / 1,264 | 1,275 / 949 | 1,144 / 1,084 |
| | Biomass (ml/l) | 18.8 | 9.6 / 22.5 | 4.4 / 8.1 | 5.7 / 15.5 | 11.1 / 24.4 | 27.8 / 41.5 | 17.0 / 23.3 | 16.1 / 17.2 |
| | No. of Genera | 12 | 8 / 12 | 7 / 10 | 9 / 6 | 4 / 8 | 11 / 12 | 15 / 12 | 16 / 15 |

* Top / Bottom

TABLE 16 (continued)
PHYTOPLANKTON DATA*

| Station | Item | CRUISE 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 3 | Total Cells (org/ml) | 4,849 / 5,825 | 764 / 1,371 | 3,181 / 5,727 | 5,853 / 5,471 | 9,543 / 5,742 | 19,515 / 16,853 | 11,952 / 12,462 | 12,778 / 15,771 |
| | Inert Diatoms (org/ml) | 1,832 / 3,429 | 254 / 543 | 1,018 / 3,817 | 1,908 / 5,417 | 1,973 / 767 | 2,221 / 2,741 | 1,264 / 3,370 | 1,516 / 6,796 |
| | Biomass (ml/l) | 15.1 / 19.8 | 8.3 / 6.8 | 8.5 / 16.5 | 16.2 / 41.9 | 34.8 / 16.7 | 71.3 / 57.8 | 21.0 / 32.1 | 13.5 / 37.1 |
| | No. of Genera | 14 / 19 | 9 / 12 | 13 / 10 | 15 / 7 | 11 / 10 | 21 / 15 | 20 / 20 | 19 / 15 |
| 4 | Total Cells (org/ml) | 2,509 | 2,038 / 1,274 | 2,544 / 9,551 | 3,754 / 4,966 | 3,628 / 5,854 | 8,237 / 9,220 | 6,936 / 11,075 | 6,809 / 7,959 |
| | Inert Diatoms (org/ml) | 1,177 | 382 / 420 | 571 / 7,704 | 64 / 1,342 | 451 / 1,141 | 646 / 1,516 | 64 / 2,991 | 448 / 1,462 |
| | Biomass (mg/l) | 11.9 | 55.5 / 26.4 | 18.5 / 54.0 | 15.4 / 25.6 | 18.6 / 23.4 | 27.8 / 34.3 | 12.0 / 37.5 | 37.5 / 21.3 |
| | No. of Genera | 12 | 15 / 6 | 7 / 8 | 14 / 9 | 9 / 10 | 13 / 15 | 12 / 17 | 9 / 9 |

* Top / Bottom

TABLE 10 (continued)

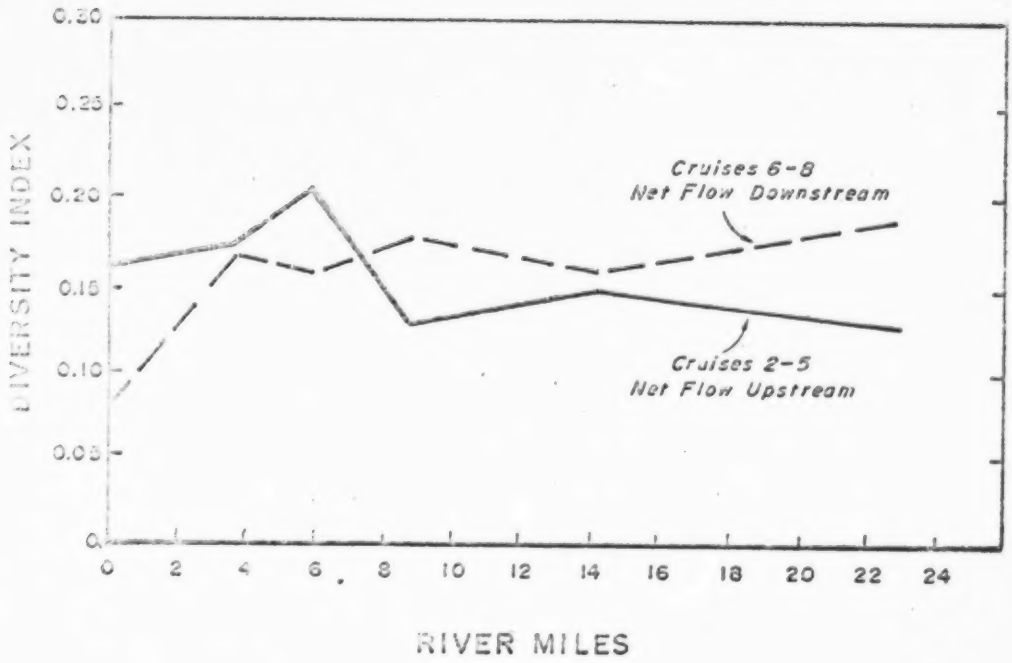
PHYTOPLANKTON DATA*

| Station | Item | CRUISE 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 5 | Total Cells | 7,491 | 8,745 | 28,170 | 41,225 | 27,096 | 16,147 | 5,030 | 5,726 |
| | Inert Diatoms | 2,096 | 2,512 | 2,980 | 14,814 | 377 | 2,110 | 634 | 957 |
| | Biomass | 20.9 | 85.6 | 51.8 | 301.8 | 53.8 | 50.8 | 8.8 | 6.3 |
| | No. of Genera | 15 | 20 | 22 | 19 | 18 | 17 | 12 | 19 |
| 6 | Total Cells (org/ml) | 12,753 / 14,650 | 11,454 / 11,482 | 12,788 / 13,235 | 10,046 / 14,183 | 9,166 / 10,432 | 13,028 / 14,120 | 6,363 / 6,678 | 3,308 / 3,819 |
| | Inert Diatoms (org/ml) | 4,862 / 5,093 | 3,689 / 4,796 | 4,379 / 4,639 | 2,858 / 5,592 | 512 / 442 | 1,528 / 2,233 | 1,225 / 3,719 | 1,018 / 755 |
| | Biomass (mg/l) | 43.8 / 45.7 | 153.2 / 145.6 | 78.6 / 78.8 | 35.7 / 46.6 | 30.3 / 47.7 | 41.5 / 46.3 | 9.8 / 14.1 | 6.3 / 7.6 |
| | No. of Genera | 19 / 17 | 20 / 16 | 17 / 16 | 16 / 15 | 13 / 13 | 20 / 15 | 14 / 16 | 9 / 12 |
| 7 | Total Cells | 27,438 | 15,968 | 17,826 | 17,753 | 22,007 | 6,171 | 4,834 | 2,480 |
| | Inert Diatoms | 8,558 | 6,621 | 1,296 | 3,640 | 1,910 | 828 | 953 | 508 |
| | Biomass | 70.4 | 73.7 | 37.1 | 21.1 | 78.7 | 11.4 | 7.5 | 3.0 |
| | No. of Genera | 27 | 22 | 17 | 19 | 18 | 19 | 15 | 7 |

* Top / Bottom

counts and biomass values for the composite samples taken from the oxidation pond from cruises 2-8. The total number of genera present at a given station was recorded and may be used in an analysis of the diversity of the population. In Figure 9, a diversity index measured as the ratio between the number of genera and the square root of the number of individuals at each station is shown. The large numbers of individuals in relation to the number of kinds of algae in the oxidation pond effluent is expected to produce a lower index in the river areas affected by the discharge. Figure 9 shows slightly higher indices in the upstream river stations when net flow was downstream and in the ship channel when net flow was upstream.

Additional sampling of bottom materials was also carried out within the deep water channel. Extensive organic deposits were found in the settling and turning basins.




Note: Station 4 not in haudraulic sequence

SAN JOAQUIN RIVER NEAR STOCKTON

PHYTOPLANKTON
DIVERSITY INDEX

DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA



FIGURE 9

TABLE II

OXIDATION POND ALGAE
ALGAL COUNTS AND BIOMASS FROM OXIDATION POND

| Cruise | Phylum | | Count org/ml | Biomass ml/l |
|---|---|---|---|---|
| 1 | - | | - | - |
| 2 | Chlorophycophyta | | 31,322 | 35.3 |
| | Euglenophycophyta | | 5,051 | 2.0 |
| | Cyanophycophyta | | 891 | 0.3 |
| | Chrysophycophyta | | 2,544 | 1.3 |
| | | Totals | 39,808 | 38.9 |
| 3 | Chlorophycophyta | | 193,775 | 118.0 |
| | Euglenophycophyta | | 60,060 | 90.5 |
| | Cyanophycophyta | | 4,760 | 0.5 |
| | Chrysophycophyta | | 106,840 | 62.1 |
| | | Totals | 365,435 | 271.1 |
| 4 | Chlorophycophyta | | 309,944 | 71.6 |
| | Euglenophycophyta | | 2,862 | 4.8 |
| | Cyanophycophyta | | 1,908 | 0.7 |
| | Chrysophycophyta | | 113,500 | 126.4 |
| | | Totals | 428,214 | 203.5 |
| 5 | Chlorophycophyta | | 133,540 | 67.1 |
| | Euglenophycophyta | | 9,540 | 28.0 |
| | Cyanophycophyta | | - | - |
| | Chrysophycophyta | | 6,488 | 6.1 |
| | | Totals | 149,568 | 101.2 |
| 6 | Chlorophycophyta | | 74,086 | 32.0 |
| | Euglenophycophyta | | - | - |
| | Cyanophycophyta | | - | - |
| | Chrysophycophyta | | 2,860 | 8.4 |
| | | Totals | 76,946 | 40.4 |
| 7 | Chlorophycophyta | | 278,308 | 157.7 |
| | Euglenophycophyta | | - | - |
| | Cyanophycophyta | | - | - |
| | Chrysophycophyta | | 4,770 | 7.4 |
| | | Totals | 283,078 | 165.1 |
| 8 | Chlorophycophyta | | 215,706 | 73.5 |
| | Euglenophycophyta | | - | - |
| | Cyanophycophyta | | - | - |
| | Chrysophycophyta | | 5,724 | 4.1 |
| | | Totals | 221,430 | 77.6 |

## DISCUSSION

The information gathered during the course of this investigation may serve to answer questions concerning the cause or causes of the dissolved oxygen problem in the San Joaquin River near Stockton. The DO depressions occurring in the Stockton ship channel in summer and autumn can be attributed to at least five factors, which may work in combination to aggravate the problem. Namely:

1. The deep, dredged channel and settling basin, which creates lower tidal velocities, longer retention times and promotes settling of suspended matter.

2. Oxygen demanding material discharged from the oxidation ponds operated by the City of Stockton.

3. Oxygen demanding material swept by the river into the region from the San Joaquin Valley.

4. Depletion of summer and autumnal flows in the San Joaquin River by storage projects and agricultural diversions.

5. Seasonal water temperature and light energy changes.

The Stockton ship channel has been progressively deepened at various times during this century, and the Corps of Engineers has recently been authorized to further deepen these waters to a depth of 35 feet. Deepening of the channel has markedly reduced the waste assimilative capacity of these waters. The reasons for this loss in assimilative capacity relate to both physical and biological processes.

The physical factors directly contributory to the reduced assimilative capacity are the increased depth itself and the diminished tidal velocity caused by the larger channel cross section. Both factors tend to depress atmospheric reoxygenation as illustrated by the following equation.

$$K_2 = \frac{(DcU)^{1/2}}{(H)^{3/2}}$$

Where $K_2$ is the reaeration rate
Dc is the molecular diffusivity of oxygen in water
H is water depth
U is water velocity

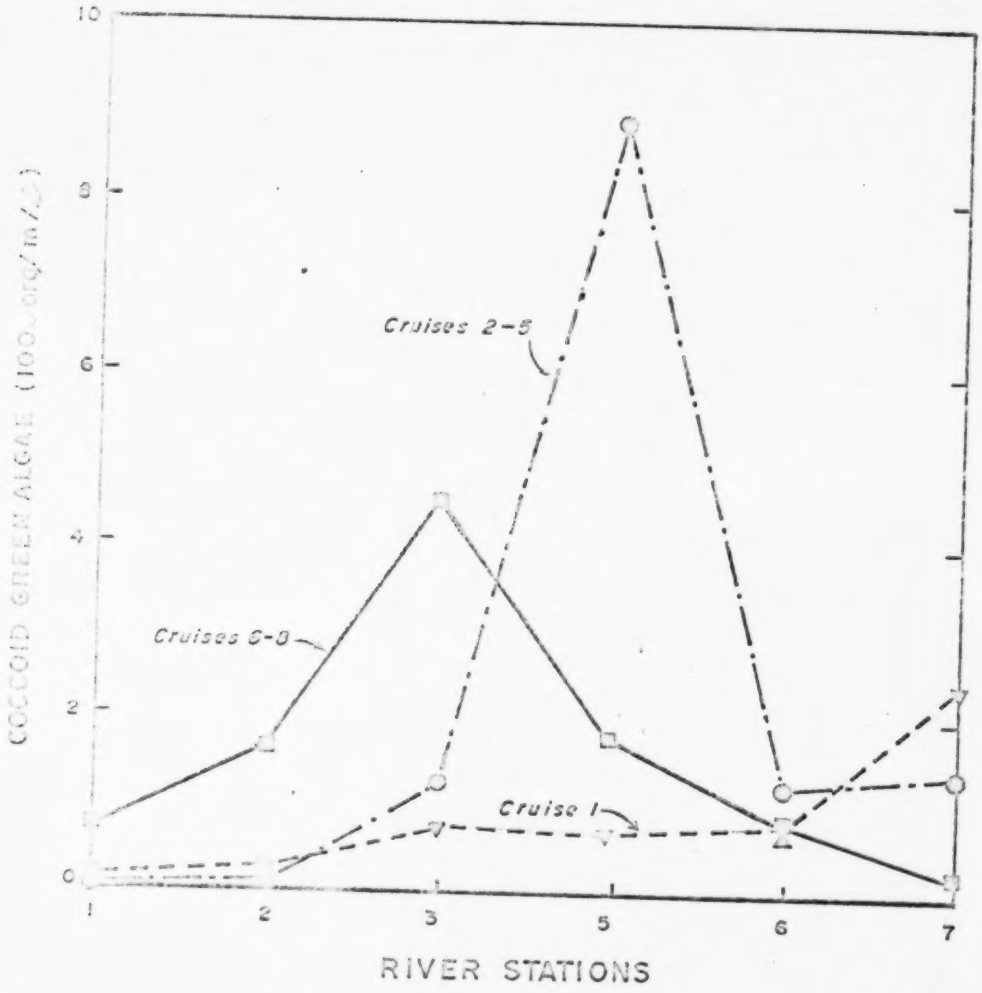
The above equation for the reaeration rate coefficient $K_2$ was developed by O'Connor and Dobbins and has been often used in oxygen balance studies. As the equation shows, reductions in velocity (U) or increases in depth (H) lead to lower $K_2$ values, implying a lower transfer of oxygen from the air to waters of depressed oxygen content.

The most important factor is biological, since the deepened channel serves as a stilling basin to collect and retain organic material entering from the river. Much of this organic material is living algae grown in the shallow, warm, well lighted, nutrient enriched river and in the large sewage oxidation ponds operated by the City of Stockton. Algal growth and photosynthetic oxygenation are efficiently carried out in the shallow river and in the ponds, but the deep turbid ship channel does not permit light energy to penetrate through enough of the water column to maintain the algal populations which are eventually trapped in the channel. As a consequence, the populations decline and respiratory demands of algae, zooplankton and bacteria prevail leading to frequent and sustained oxygen depressions in the lower depths during the summer and fall.

The natural flora of the San Joaquin River are primarily diatoms. The "Natural" river flora is altered in the vicinity of the Stockton sewage treatment plant by high concentrations of other algal groups principally the coccoid green algae. Figure 10 compares the coccoid green algal populations in the river for cruise 1, cruises 2-5 and cruises 6-8. If cruise 1 can be taken as typical of a summer condition at a time when no oxidation pond discharge occurs, the algae populations present around river stations near the outfall after cruise 1 dramatize the build-up of green algae from the pond effluent. After the river flow was increased the green algal buildup shifted downstream and was diluted. In addition to algae, the oxidation ponds contribute ammonia to the river which in turn demands oxygen when oxidized to nitrate.

In the shallow river reach where light is abundant through most of the water column, the living planktonic algae produce a surfeit of oxygen through photosynthesis. High rates of photosynthesis and reaeration in the shallow river area often maintain supersaturated DO levels. A high oxygen demand is also present in the river (see Table 4), but this is overpowered by photosynthesic and reaeration processes. In the deep, turbid ship channel the reverse is true, and during summer and autumn respiratory demands often outweigh photosynthetic and atmospheric oxygen contributions.

What is the fate of these algal organisms? A balance of the number of coccoid green algae discharged from the pond and population in the river above a base level set by cruise 1 indicates that, at best, this type of organism survives in a recognizable form in the river for only one or two days. The green algae may be consumed by grazing zooplankton, settle and decompose on the river bottom or decompose in the ship channel waters. An analysis of inert diatom shells at stations 1, 2 and 3 indicates that dead cells make up a higher percentage of the total population near the bottom as compared with the surface samples. At station 3, 34 percent of the surface sample counts are dead as compared with 69 percent near the bottom. Population levels are generally alike except that higher levels are observed regularly near the bottom reflecting, quite probably, the sinking of dead diatoms along with other detritus.




Note: Station 4 not in hydraulic sequence.

SAN JOAQUIN RIVER NEAR STOCKTON

DISTRIBUTION OF
COCCOID GREEN ALGAE

DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA



FIGURE 10

Zooplankton populations were measured by the California Department of Fish and Game during the study period. Higher concentration of zooplankton organisms were found in the Stockton area than in any other area sampled in the Sacramento-San Joaquin Delta region. The June-August period (when net upstream movement occurred) showed high zooplankton count both immediately upstream from the Stockton pond discharge point and in the ship channel. Later when net downstream flow occurred in the fall comparable zooplankton populations were present in the ship channel, but zooplankton populations were reduced in the area upstream from the pond discharge. In each case, the populations in the ship channel were least 100 times as great as at Mossdale Bridge (Station 7) farther up river (3). The zooplankton netting methods employed did not pick up all grazing organisms, but yielded principally the larger adult animals (including larger rotifers).

The impact of flow depletions and resulting flow reversals and lengthened residence times in the Stockton channel are apparent considering the results of the flow releases and the impact of deoxygenation processes in the deep water channel. These processes are further aggravated by water temperature increases which increase respiratory demands, while reaeration rates and dissolved oxygen saturation values fall. The combined effect can be expected to produce lower in situ DO values in the channel although organic loadings (as measured by BOD or COD) may remain the same. To further aggravate the picture, photosynthetic contributions can be expected to wane as summer wears on since the hours of daylight diminish from the vernal maximum.

In summary, flow depletions and channel deepening have reduced the waste assimilative capacity of the Stockton ship channel. Organic matter (including algae) accumulates in the channel where respiratory oxygen demands of bacteria, algae and zooplankton exceed surface reaeration and photosynthetic oxygen sources. Algal crops from the oxidation ponds and from the enriched river south of the study area constitute much of the original oxygen demand swept into the channel.

The long term oxidation of organic matter within the ship channel exceeds that measured by the standard 5 day BOD test. A more realistic measure might be the ultimate oxygen demand (UOD) as described by Gameson (4):

$$UOD = 2.67\ C + 4.57\ N$$

where
- C is the organic carbon content
- N is the unoxidized nitrogen content ($NH_3$ + organic)

Long term BOD tests (up to 30 days) were run by the California Department of Water Resources in 1962. These tests yielded 20 day BOD values of 9.0 - 17 mg/l at the Mossdale Bridge in July-September 1962. Where longer tests were performed still higher values were achieved (15-20 mg/l by approximately 30 days). These values are 2-4 times the 5 day BOD values in Table 4. Residence times in the Stockton channel exceed 30 days for a flow of 200 cfs.

Computations of UOD from both river and oxidation pond sources based on water quality and flow data, indicated that the UOD from these two sources may be approximately equal during the fall canning season when river flows are low. An example of such a calculation with river and waste quality assumptions is furnished as Appendix A.

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# APPENDIX A

Example of Ultimate Oxidation Demand (UOD) Computation for San Joaquin River and Stockton Oxidation Ponds.

DATA SOURCES

a) FWPCA-CVWQCB water quality survey data (July-October 1964).
b) DWR Delta-Suisun Bay Investigation water quality data (unpublished).
c) Bailey, T., "Limnology of a Polluted Estuary," AAAS-ASL&O meeting, Riverside, California, June 1965.

Purpose of this analysis:

To separate the oxidizable materials contributed by the San Joaquin River upstream of the Stockton area from oxidizable materials in the Stockton STP effluent as found during the summer-autumn period and the estimate of the total pounds/day (UOD) of oxidizable material from each source.

Assumptions:

1) Typical net downstream flow past Stockton - August - October estimated as 200-400 cfs.

2) Quality of San Joaquin River in Mossdale-Vernalis reach typifies river contributions during above time and flow condition. Quality taken to be:

   Organic nitrogen - 0.8 mg/l (a)
   Ammonia nitrogen - 0.1 mg/l (a)

   (a) Based on data sources a & b

3) Quantity of Stockton STP effluent during August-October season taken to be 30 MGD.

4) Quality of Stockton STE effluent assumed to be as follows:

   Organic nitrogen - 5.1 mg/l (b)
   Ammonia nitrogen 4.5 - 22 mg/l (c)

   (b) Based on data source a (average value)
   (c) Based on data sources a & c

5) Carbon-nitrogen ratio of 7 for algae

C) Gameson's equation for UOD based on oxygen necessary to satisfy carbonaceous and nitrogenous demand.(d)

$$UOD = 4.57 (N) + 2.67(C)$$

(d) Gameson and Wheatland, "The Ultimate Oxygen Demand and Course of Oxidation of Sewage Effluents" - Inst. Sewage Purification, 1958.

Calculations:

A. River

1. UOD (mg/l) = 4.57(0.1+0.8)+2.67(0.8)(7) = 19.05

use 20 mg/l

2. pounds UOD/day

@ 200 cfs

$$200 \times 62.4 \times 3600 \times 24 \times \frac{20}{10^6} = 21{,}900 \text{ lbs/day}$$

@ 400 cfs

$$400 \times 62.4 \times 3600 \times 24 \times \frac{20}{10^6} = 43{,}800 \text{ lbs/day}$$

B. Stockton STP

1. UOD (mg.l)
organic N
4.57 (5.1) + 2.67 (5.1)(7) = 118.8 mg/l
ammonia N
4.57 (4.5) = 20.6 mg/l
4.57 (22) = 100.5 mg/l

UOD of effluent 139.4 - 219.3 mg/l
as calculated for $NH_3$ ranges.

2. Pounds of UOD/day

$$30 \times 1.547 \times 62.4 \times 3600 \times 24 \times \frac{139.4}{10^6} = 34{,}800 \text{ lbs/day}$$

" " " " " $\frac{219.3}{10^6} = 54{,}600$ lbs/day